NASA Contractor Report 172425

(NASA-CR-172425) PROPELLER AIRCRAFT INTERIOR NOISE MODEL: USER'S MANUAL FOR COMPUTER PROGRAM Final Report (Bolt, Beranek, and Newman, Inc.) 59 p CSCL 20A N87-18402
Unclas
G3/71 43384

IN-71
58135
DATE OVERRIDE
P-59

# Propeller Aircraft Interior Noise Model – Users' Manual for Computer Program



E.G.Wilby and L.D.Pope

Bolt Beranek and Newman Inc.
Canoga Park, CA 91303

Contract NAS 1-15782
JANUARY 1985 .

Date for general release January 31, 1987

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

## TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

## LIST OF FIGURES

## 1.0 SUMMARY


A computer program entitled **PAIN** (an acronymn for Propeller Aircraft Interior Noise) has been developed to permit calculation of the sound levels in a model of a cabin of a propeller-driven airplane. The model fuselage is a cylinder with a structurally integral floor. The cabin sidewall and floor are stiffened by ring frames, stringers and floor beams of arbitrary configurations. The cabin interior is covered with a trim (i.e., insulation with a lining) to increase the sidewall sound isolation and provide absorption in the cabin.

The propeller noise of concern is actually a series of tones that occur at the blade passage frequency and at integral multiples of that frequency (i.e., at its harmonics). The program permits the calculation of the space-average interior sound levels for the first ten (10) harmonics of a propeller (of any design) rotating alongside the fuselage.

The input data required by the program include the mechanical and acoustical properties of the fuselage structure and sidewall trim. Also, the precise propeller noise signature must be defined on a grid that lies in the fuselage skin. The propeller data have to be generated with a propeller noise prediction program for example, the NASA Langley ANOPP program [1]).

## 2.0 INTRODUCTION

The present program mechanizes an analytical model presented in Reference [2]. Details of the underlying theory on which this program is based are available in that report.

The two primary elements of the interior noise model are the fuselage and the propeller (Figs. 1 and 2). The fuselage consists of a cylinder stiffened by ring frames and stringers, and a floor that is structurally an integral part of the fuselage. The cabin space is the volume above the floor. The interior surface of the cabin (sidewall) is finished out with a trim consisting of insulation covered with a lining. The propeller rotates about an axis parallel to the centerline of the fuselage. The model can be used to predict the space average sound levels in the cabin space for each of the various harmonics of the propeller (up to a maximum of ten (10) harmonics).

The present model works with the pressure time histories (signatures) as defined over the fuselage at a number of closely spaced points on a grid that lies in the fuselage skin (Fig. 3). The pressure signatures are input as Fourier series that define the amplitudes and phases of each of the harmonics of the propeller (at each location on the grid).

The fuselage structural modes are developed for the case of a stiffened cylinder with a floor partition. The structural properties of the cylinder and floor are required as input data. The structural modes are described by the computed resonance frequencies and mode shapes, and by associated structural loss factors. The loss factors of the modes of a bare fuselage must be input and must come from measurements (or be estimated). When trim is installed on the sidewall, the structural losses increase due to the trim's presence against the sidewall and this is computed for the particular trim installation.

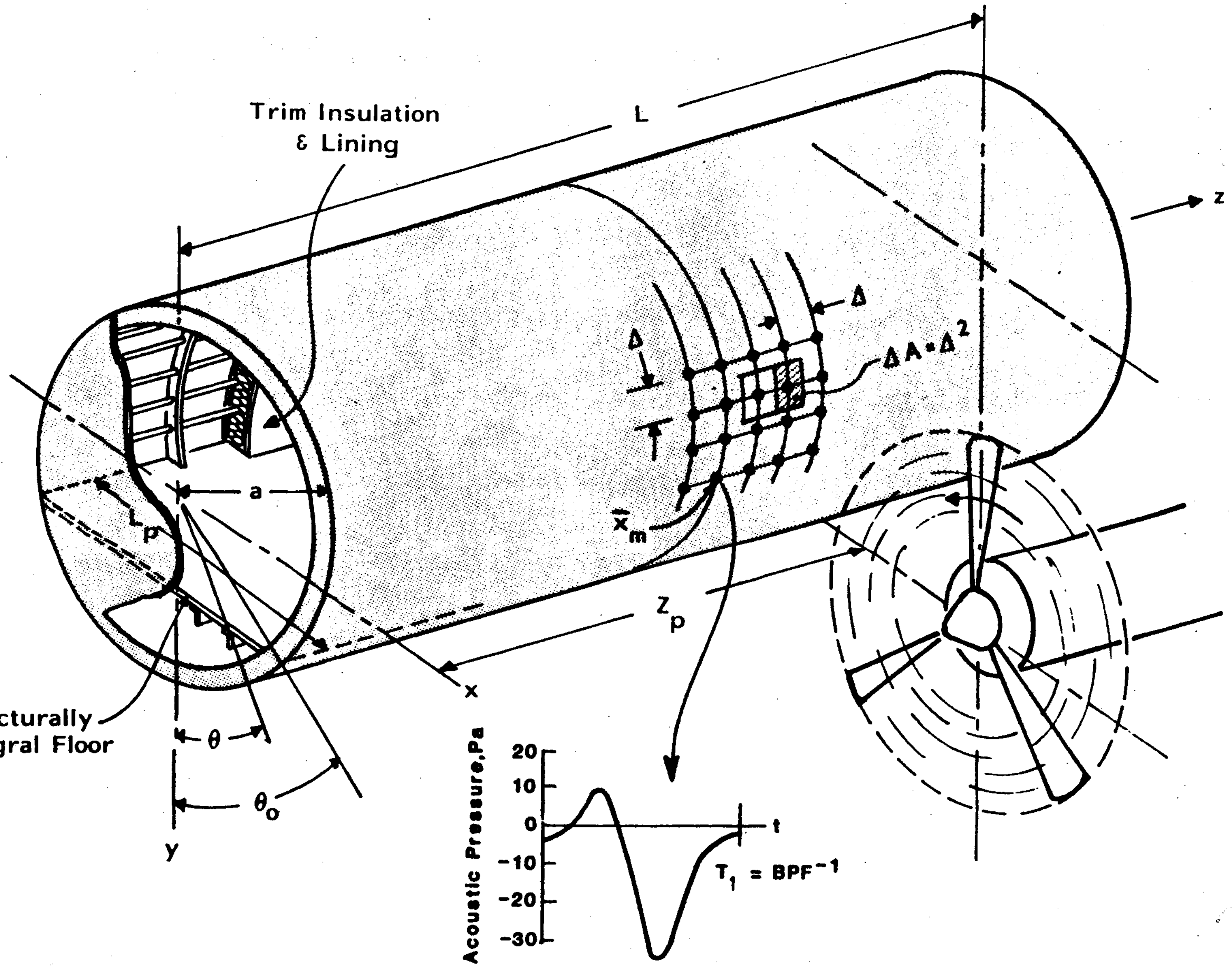


FIGURE 1. PROPELLER AIRCRAFT INTERIOR NOISE MODEL

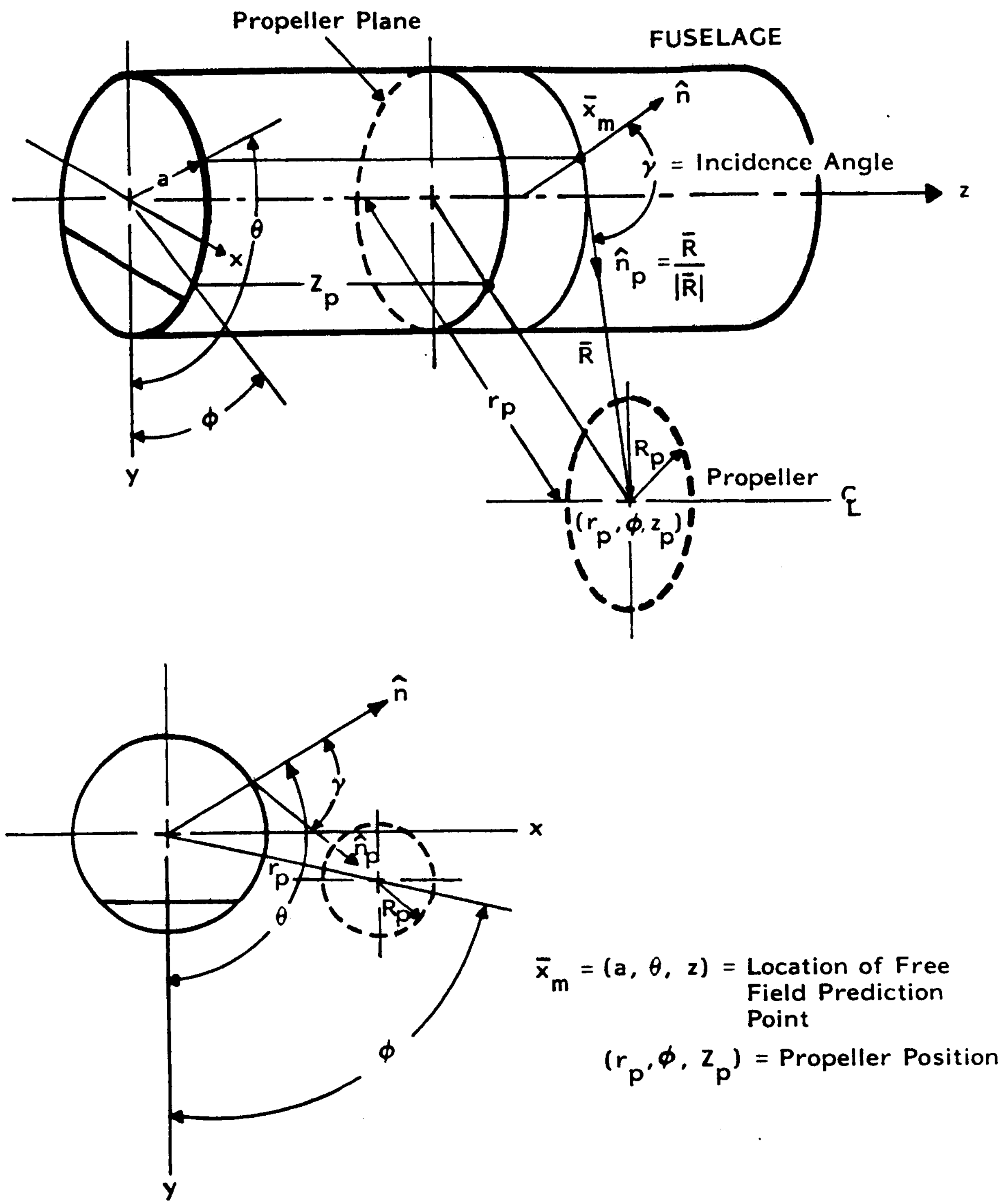


FIGURE 2. PROPELLER AND FUSELAGE SURFACE POINT GEOMETRY

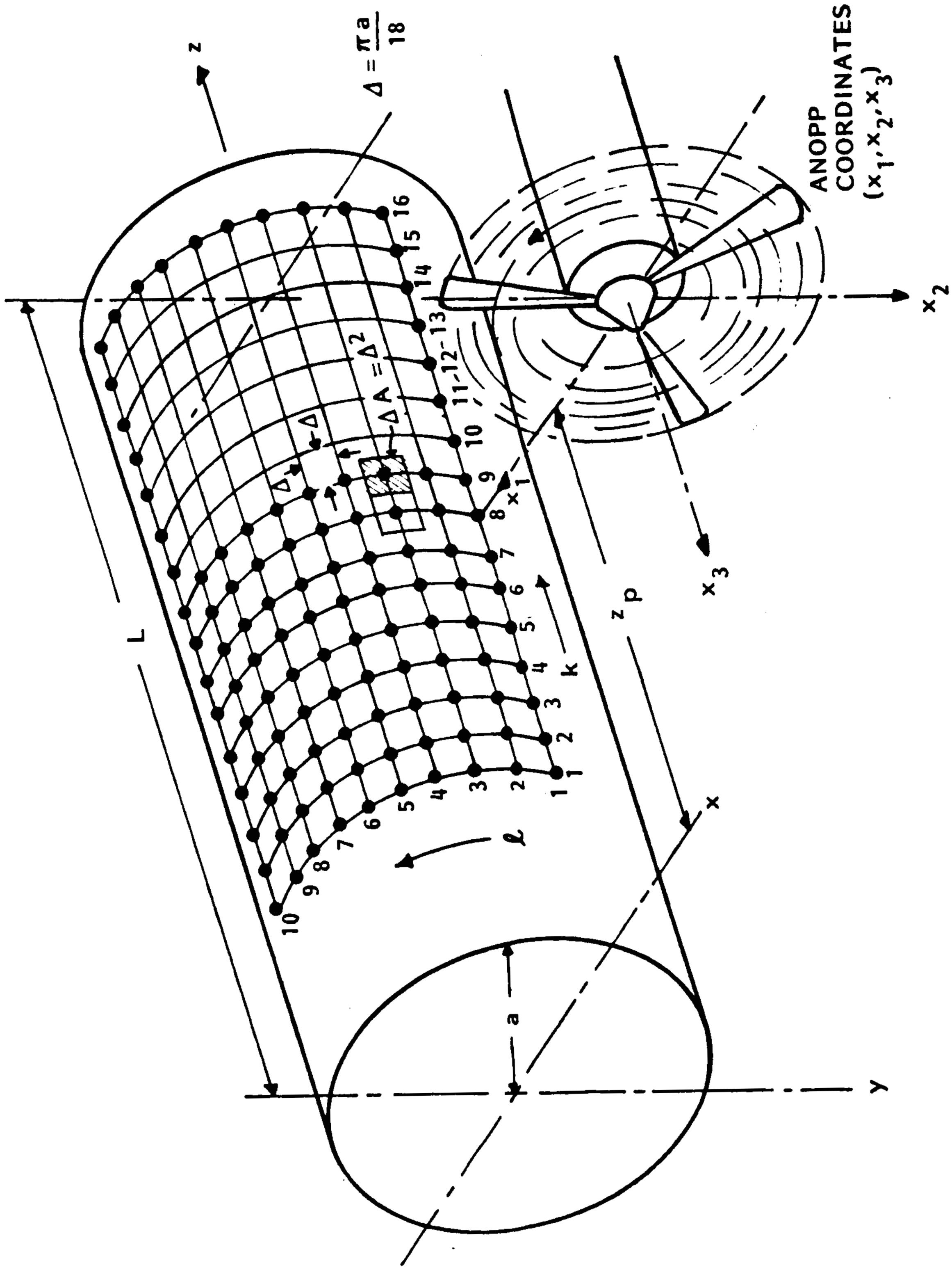


FIGURE 3. GRID USED FOR PROPELLER NOISE PREDICTIONS

The acoustic modes of the cabin space are similarly defined by the resonance frequencies, mode shapes, and loss factors. The acoustic loss factors must be input for a bare fuselage but are calculated when a cabin trim is installed.

The effects introduced by the trim at a given frequency are computed using the values of the wave impedance and complex acoustic wavenumber in the insulation, and the trim lining surface weight and loss factor.

## 3.0 MODELS

One can begin to construct an input card package once the basic size of the fuselage is known and the location of the propeller defined. The overall geometry must be fixed so that the grid that will lie in the fuselage skin (Fig. 3) can be located. The grid is used for specification of the propeller noise excitation. The propeller-induced pressure signature at each location on the grid is required, and a propeller noise prediction program such as the NASA Langley ANOPP program [1] will have to be used to make these predictions. Obviously, the propeller diameter, rpm, number of blades, blade shapes, aircraft forward speed, etc., will be needed for these calculations. The program PAIN uses free-field data as input and a coefficient is applied to the free-field amplitudes in a crude attempt to model the surface reflections caused by the fuselage. If a propeller noise prediction program that takes into account the reflection from a rigid cylinder located nearby is used, the surface reflection corrections applied in the present program can be removed and the new type of propeller data can be input, just as is done at present with the free-field data.

After the propeller data are generated, the remainder of the input requirements are associated with the definition of the fuselage structure and the trim on the cabin sidewall.

The following is a step-by-step procedure used to parameterize the interior noise model:

1) Referring to Fig. 2, define the propeller hub position alongside the fuselage by the coordinates $(r_p, \phi, z_p)$. The dimension $r_p$ is the radial distance from the center of the fuselage cylinder to the axis of rotation of the propeller. $\phi$ defines the angular position relative to the bottom of the fuselage. The location of the propeller relative to the front of the cylinder is given by $z_p$. The basic fuselage configuration is fixed by three dimensions--the cylinder length L, radius a, and the position of the floor as defined by the angle $\theta_o$ (see Figs. 1 and 3).

2) The grid used for the propeller noise predictions must next be located in the skin. The grid is defined over one-quarter of the periphery of the cylinder. Three coordinates of concern are the so-called ANOPP coordinates $(x_1, x_2, x_3)$ in Fig. 3. For purposes of defining the coordinates of the grid points $(k, \ell)$, the coordinate $x_1$, whose origin is at the propeller hub, will always penetrate the fuselage perpendicularly and that point of penetration will establish the line $(\ell = 1)$. The coordinate positions are then given by the following relations for $k = 1, k_{max}$, and $\ell = 1, 10$:

$$(k,\ell) \leftrightarrow (x_1^{\ell}, x_2^{\ell}, x_3^{k})$$

where $x_1^{\ell} = (r_p - a) + a\{1-\cos[(\ell-1)\pi/18]\}$

$$x_2^{\ell} = -a \sin[(\ell-1)\pi/18]$$

$$x_3^{k} = (\pi a/18)[k_p - k] \quad .$$

$k_p$ is the k index of the grid point $(k,\ell) = (k_p,1)$, that is, where the coordinate $x_1$ penetrates the fuselage. For example, for $k_{max} = 16$ as in Fig. 3, setting $k_p = 8$ roughly centers the grid longitudinally about the propeller plane. Note that the value of $(\pi a/18)\cdot[k_p - 1]$ cannot exceed $z_p$. Similarly, the chosen value of $k_{max}$ should be such that $(\pi a/18) \times [k_{max}-1] < L$. This will assure that all grid points are on the cylinder.

3) The propeller noise at each location $(k, \ell)$ will be periodic with period $T_1 = BPF^{-1}$ where BPF is the blade passage frequency

$$BPF = \frac{NB}{60},$$

where N is the rpm and B is the number of blades. The propeller noise at each location on the grid, over the period $t = 0$ to $T_1$, is (Eq. (33) of Ref. 2).

$$p[(k,\ell),t] = \frac{a_o^{(k,\ell)}}{2} + \sum_{H=1}^{\infty} A_H^{(k,\ell)} \cos\left(\omega_H t - \phi_H^{(k,\ell)}\right).$$

$a_o^{(k,\ell)}/2$ is just the mean pressure and is of no concern. However, the two coefficients $A_H^{(k,\ell)}$ and $\phi_H^{(k,\ell)}$ must be defined. Fourier analysis of the computed pressure time histories over the blade passage period $T_1$ is necessary to provide the first ten (10) harmonics. The coefficients $A_H$ and $\phi_H$ for each position $(k,\ell)$ are given by Eqs. (31) and (32) of Ref. 2.

4) The structural properties of the fuselage cylinder and floor are required next. These data consist of the following:

   a) The elastic modulii E and Poisson's ratios $\nu$ of the materials composing the cylindrical shell and the floor plate.

b) The equivalent thicknesses t of the shell and of the plate. These are given by the formula

$$t = t_i + \frac{A_s}{d} + \frac{A_R}{\ell},$$

where $t_i$ is the actual thickness of the skin of the shell (or the plate thickness), $A_s$ is the cross-sectional area of the stringers on the shell (or the longitudinally running floor beams), d is the spacing between stringers (or floor beams), $A_R$ is the cross-sectional area of the ring frames on the shell (or the transverse floor supports), and $\ell$ is the spacing between rings (or floor supports). Both the shell and plate must have a constant thickness, and the cross-section is uniform along the length of the cylinder.

c) The bending rigidities of the stringers (or longitudinal beams) and the ring frames (or floor supports) divided by the spacings, i.e.

$$\left.\frac{EI}{d}\right)_{\text{stringer}} \quad ; \quad \left.\frac{EI}{\ell}\right)_{\substack{\text{ring}\\\text{frame}}}$$

and

$$\left.\frac{EI}{d}\right)_{\substack{\text{long.}\\\text{floor}\\\text{beam}}} \quad ; \quad \left.\frac{EI}{\ell}\right)_{\substack{\text{floor}\\\text{support}}}$$

The area moments of inertia of the stiffeners I are to be computed about the centerline of the skin (or plate) to which they are attached. If the stiffeners are not identical or not equally spaced, typical or average values should be used for the bending rigidities/unit width.

d) The average surface mass $m(kg/m^2)$ of the cylinder wall (or floor plate), i.e,

$$m = \rho t,$$

where $\rho$ is the density of the material and t is the equivalent thickness as defined in (b) above.

5) Having defined the structural properties of the fuselage cylinder, the modes of the fuselage are calculated using displacement series (see [2], Appendix D). The shell displacement in mode r is of the form

$$\psi_s^r(z,\theta) = \sin\frac{M\pi z}{L} \sum_{n=0}^{n*} C_{Mn}^{sr}(-1)^n \cos n\theta \;\; (\text{or} (-1)^{n+1} \sin n\theta)$$

for symmetric or antisymmetric modes, and for the floor,

$$\psi_p^r(z,x) = \sin\frac{M\pi z}{L} \sum_{n=0}^{n*} C_{Mn}^{pr} \cos\frac{n\pi x}{L_p} \quad (\text{or } \sin\frac{n\pi x}{L_p})$$

where M = number of longitudinal half-wavelengths (Max 15)
n = number of shell circumferential waves (Max 14) or number of half-wavelengths in floor width (Max 8).
n* = number of terms in displacement series for shell or floor

The symmetric modes and antisymmetric modes are calculated separately, for the same range of values of M and n. The cylinder is assumed to be supported at both ends by shear diaphragms.

6) Next come the geometrical properties of the cabin space which are given entirely by the cavity length $L_c$, radius a, and the floor angle $\theta_o$. It is not necessary that the cavity length be equal to the structure length L. A variable d is defined that is the difference in the z coordinates between the start of the cavity and the start of the structure and is positive if $L < L_c$. Usually L will be equal to or greater than $L_c$ and d will be zero or negative.

7) There are certain data that pertain to the trim installation, namely

a) The wave impedance of the insulation

$$W = |W| e^{i\phi},$$

and the complex acoustic wavenumber

$$\gamma = \alpha - ik,$$

where

$$k = 2\pi / \lambda_m,$$

and $\lambda_m$ is the acoustic wavelength in the material.

b) The trim lining mass per unit area $m_t$ and the flexural loss factor $\eta_t$ of the lining.

The wave impedance is given by the amplitude $|W|$ in mks rayls and the phase $\phi$ in degrees. The attenuation constant $\alpha$ is input in dB/m and the acoustic wavelength $\lambda_m$ in meters. The data are, of course, frequency-dependent. They are read in as a table at one-third octave band center frequencies. In the case of propeller noise prediction, the blade passage frequency and its harmonics will fall at frequencies set by the propeller speed and number of blades. In such a calculation, the frequency bands have no purpose other than defining the frequencies for the data required for the trim. The insulation properties needed at the frequencies of the tones (i.e. the BPF and its harmonics) are interpolated from the input at the band center frequencies. Data for a standard aircraft glass fiber insulation are given in Appendix A of Ref.[2].

8) When the acoustic and structural modal densities are large enough, the transmission can be expected to be dominated by modal response close to the excitation frequency. High frequency formulations have been developed in Ref.[2] as an approximation in this case. These approximations result in a considerable saving in computation time.

If the change from low frequency to high frequency formulation is desired at and above a given frequency, this frequency must be specified in Program PAIN. Three options are available for this.

a. If the input frequency is zero, the program estimates a change over frequency based on the volume of the cavity. The frequency is the 1/3 octave band center frequency in which the following empirical value lies.

$$f = \frac{4.1\ c_{oI}}{\sqrt[3]{V}}\ \text{Hz}$$

where $V$ = cavity volume ($m^3$)

$c_{oI}$ = Interior speed of sound (m/sec).

b. If the input frequency is greater than the maximum 1/3 octave band center frequency or propeller harmonic frequency, the low frequency formulation is used throughout.

c. If any other frequency is input, the program uses the high frequency formulation at and above the first 1/3 octave band center frequency in which the input frequency lies.

It should be noted that the high frequency formulation (expected value) is calculated at all possible frequencies and output as supplementary information, although not necessarily valid at low frequencies. For tone transmission, a bandwidth of 7% has been used to define structural modes close to the propeller harmonic.

## 4.0 OVERALL PROGRAM DESCRIPTIONS

The master (main) program PAIN that computes the interior noise levels uses data that are generated by four auxiliary programs. One of these programs calculates the acoustic modal characteristics of the cabin, two other programs the structural modal characteristics of the fuselage, and a fourth the propeller noise field.

The acoustic modes are calculated with the program CYL2D. The only input required by CYL2D is a single card to define the floor angle $\theta_o$. The acoustic modes are determined for a two-dimensional case (i.e. $q = 0$) and a radius $a = 1$ meter. The resonance frequencies and mode shapes are computed and the mode shapes normalized for use by the main program. The values that the eigenvectors take on the periphery of the cabin are extracted and then ordered in sequence of boundary points. A code is used to identify symmetric and anti-symmetric modes (1 = symmetric, 0 = anti-symmetric). These conditioned data are written on a file (tape) for recall by the main program. Appendix C of Ref.[2] may be consulted for more details of the calculations performed by CYL2D.

The structural modal data are provided by a program called MRPMOD whose output is also to a file (tape) read by PAIN. MRPMOD requires input data in the form of cards that define the number of generalized coordinates used in the structural analysis program, the maximum number of axial halfwaves (presently $M = 10$), the number of generalized coordinates retained to develop an accurate structural mode shape, the cylinder length, and finally the cylinder and floor masses per unit of area. In addition, MRPMOD reads two files (tapes) which are output from the fundamental structural program MRP (MRP stands for M. R. Peterson who developed the original analysis for the floor partitioned cylinder). The program MRP reads data cards that define the properties of the shell and floor plate materials, masses per unit of area, stiffener bending rigidities, and alphameric information that directs the program's calculations and output. MRP must be run twice--once for the symmetric modes and once for the anti-symmetric modes. The two files (tapes) created by these runs are read by MRPMOD. The files (tapes) contain the computed mode shapes and resonance frequencies. MRPMOD takes the output from MRP, calculates the generalized masses, rank orders the modes by frequency, and selects the most significant generalized coordinates, that is, those needed to recreate the structural mode shapes where required in PAIN. Table D-1 of Appendix D of Ref.[2] gives an example of MRPMOD output.

The propeller noise data must be calculated with a propeller noise prediction program, such as ANOPP [1]. This auxiliary program is neither part nor parcel of PAIN as are the programs CYL2D, MRP, and MRPMOD. Propeller noise data must presently be input to the main program as a card deck that contains (in a sequence to be specified exactly in Sec. 5) the location of the grid points $(k,\ell)$ of Fig. 3 and the corresponding free-field Fourier amplitudes and phases of each propeller harmonic at each location of the grid.

The programs CYL2D and MRPMOD do not call any subroutines. MRP and PAIN each has a large number of subroutines. The flow chart that follows in Figure 4 shows the basic sequence of input manipulation, computation, and output in the main and auxiliary programs.

## PROPELLER AIRCRAFT INTERIOR NOISE COMPUTER PROGRAMS

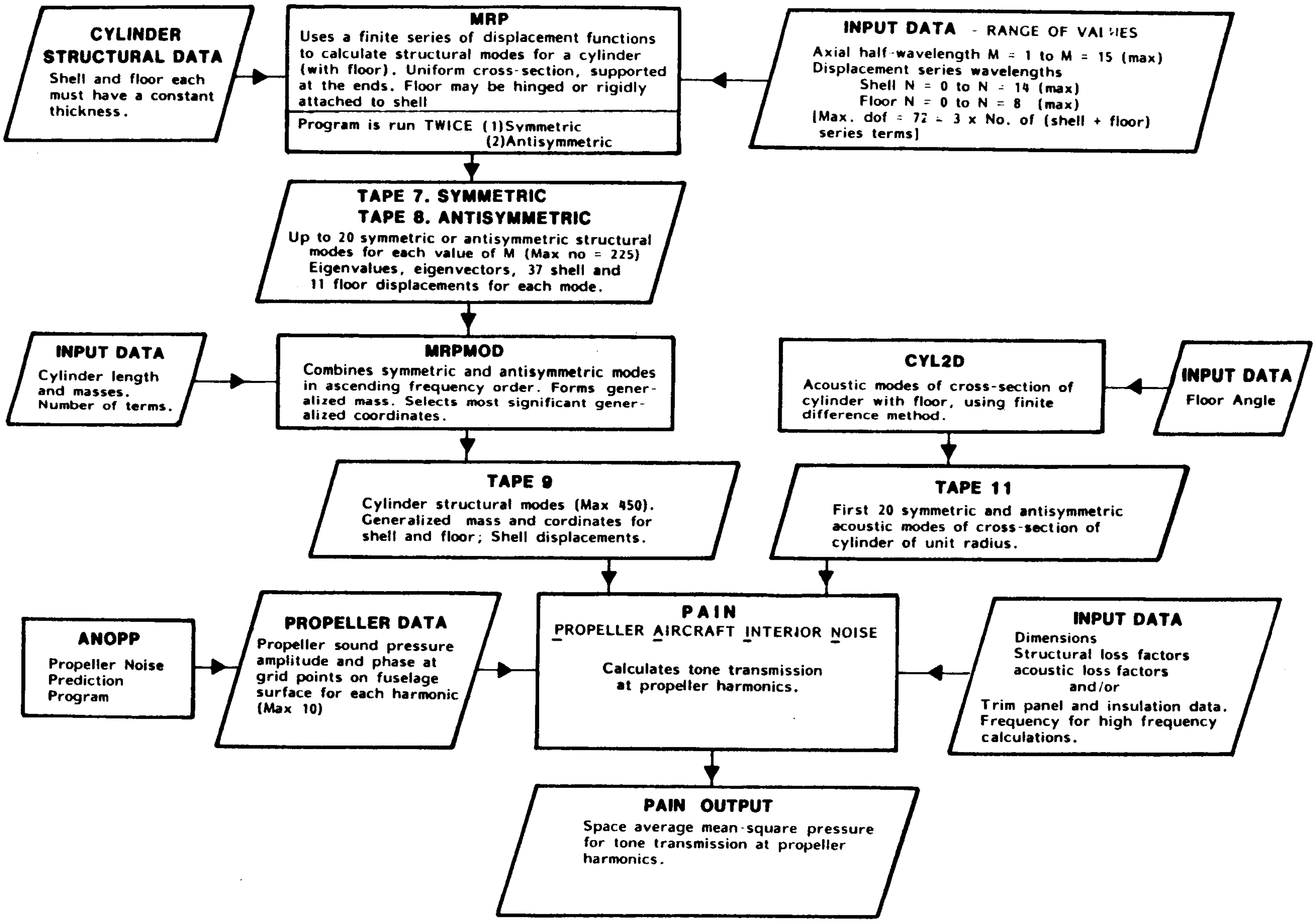


FIGURE 4. FLOW CHART FOR PROGRAMS

## 5.0 INPUT DATA

The following is a card-by-card description of the input for the programs CYL2D, MRP, MRPMOD, and the main program **PAIN**. All input is in metric units, with angles in degrees.

### 5.1 Program CYL2D

#### 5.1.1 Input Data

| Card | Columns | Format | Description |
|---|---|---|---|
| 1 | 1 - 10 | F10.3 | Floor Angle, $\theta_o$ (see Figure 1) |
| 2 | 1 | 6/7/8/9 | End of File |

The program CYL2D requires the IMSL library subroutines EIGRF, LINV2F, VMULFF, VSRTR and VSRTU.

#### 5.1.2 Output File, Tape 11

The output file, Tape 11, must be cataloged or stored for input to program **PAIN**. Tape 11 contains

Floor Angle
Locations at which eigenvectors are specified
First 20 eigenvalues (symmetric and antisymmetric combined)
Generalized masses
Eigenvectors for both interior and boundary locations

#### 5.1.3 Printed Output

Eigenvector locations, for cylinder interior and boundary.
Eigenvalues for first 20 modes (symmetric and antisymmetric combined) for cylinder with unit radius of 1 meter. Graphical presentation of eigenvectors.
Generalized masses and eigenvectors.

## 5.2 Program MRP

### 5.2.1 Input Data

| Card | Columns | Format | Description |
|---|---|---|---|
| 1 | 1-80 | 20A4 | Title cards (as many as required). These are printed directly on the output but not on Tape 7 output. |
| 2 | 1-33 | A3 | END |
| 3 | 1-10 | A10 | INPUT DATA |
| 4 | 1-7 | A7 | GENERAL |
| 5 | 6-21 | 4A4 | FREELY SUPPORTED<br>Shear diaphragms at ends of cylinder. |
| | 36-43 | 2A4 | RIGID or HINGED<br>Joint condition for Floor-Cylinder Junction. |
| | 66-80 | 3A4,A3 | SYMMETRIC or ANTISYMMETRIC<br>Symmetry about a vertical axial plane of the modes required. |
| 6 | 6-20 | E15.0 | Angle $\theta_o$ (degrees) at which the floor joint is located ($\theta_o$ = 0 is the bottom centerline). |
| 7 | 6-10 | I5 | Starting value of M=1 in the displacement series. |
| | 11-15 | I5 | Final value of M (Maximum no. = 15) (Max.M x No. of eigenvectors $\leq$ 225) |

| Card | Columns | Format | Description |
|---|---|---|---|
| 7 (Contd) | 16-20 | I5 | Increment for M = 1. M = number of longitudinal half-wavelengths. |
| | 21-25 | I5 | Starting value of $n_s$=0 in shell circumferential displacement series. |
| | 26-30 | I5 | Final value of $n_s$ for shell (Maximum no. = 14). |
| | 31-35 | I5 | Increment for $n_s$ = 1. $n_s$ = no. of shell circumferential waves |
| | 36-40 | I5 | Starting value of $n_p$ = 0 in floor width displacement series. |
| | 41-45 | I5 | Final value of $n_p$ for floor (Maximum no. = 8). |
| | 46-50 | I5 | Increment for $n_p$ = 1. $n_p$ = no. of half-wavelengths in floor width. |
| 8 | 6-10 | L5 | T = logical value true. Shell u and v degrees of freedom included. |
| | 11-15 | L5 | Y = logical value true. Floor u and v degrees of freedom included. |
| | 16-20 | L5 | F = logical value false. No extra printing required. |
| 9 | 1-5 | A5 | SHELL. Shell structural data. |
| 10 | 6-20 | E15.0 | $E_x$($N/m^2$) Modulus of elasticity in the axial direction. |

| Card | Columns | Format | Description |
|---|---|---|---|
| 10 (Contd) | 21-35 | E15.0 | $E_\theta$ (N/m$^2$) Modulus of elasticity in the circumferential direction. |
| | 36-50 | E15.0 | $\nu_x$ Poisson's ratio |
| | 51-65 | E15.0 | $\nu_\theta$ Poisson's ratio |
| | 66-80 | E15.0 | $G_{x\theta}$ (N/m$^2$) Shear modulus. For isotropic materials, if $G_{x\theta}$ is blank, it is computed using $G = E/2(1+\nu)$ |
| 11 | 6-20 | E15.0 | Thickness of shell (m). Includes "smeared-out" stiffener areas. |
| | 21-35 | E15.0 | Shell mass/unit area (kg/m$^2$) including "smeared-out" stiffener masses. |
| | 36-50 | E15.0 | Radius of shell (m) |
| | 51-65 | E15.0 | Length of shell (m) |
| 12 | 6-20 | E15.0 | $D'_{xs} = \left[\frac{EI}{d}\right]_{\text{stringer}} - \frac{E_x(t^3 - t_i^{\,3})}{12(1-\nu^2)}$ (N.m) Additional bending rigidity of shell stringers/stringer spacing. |
| | 21-35 | E15.0 | $D'_{\theta R} = \left[\frac{EI}{\ell}\right]_{\substack{\text{ring-}\\\text{frame}}} - \frac{E_\theta(t^3 - t_i^{\,3})}{12(1-\nu^2)}$ (N.m) Additional bending rigidity of shell frames/frame spacing. (Moments of inertia of stringers or frames to be computed about shell centerline) |

| Card | Columns | Format | Description |
|---|---|---|---|
| 13 | 1-5 | A5 | PLATE Floor structural data |
| 14 | 6-20 | E15.0 | $E_x$ ($N/m^2$) Modulus of elasticity in the axial direction |
| | 21-35 | E15.0 | $E_y$ ($N/m^2$) Modulus of elasticity in the transverse direction |
| | 36-50 | E15.0 | $\nu_x$ Poisson's ratio |
| | 51-65 | E15.0 | $\nu_y$ Poisson's ratio |
| | 66-80 | E15.0 | $G_{xy}$ ($N/m^2$) Shear modulus. If blank, it is computed using $G = E/2(1+\nu)$. |
| 15 | 6-20 | E15.0 | Thickness of floor (m) includes "smeared-out" stiffener areas. |
| | 21-35 | E15.0 | Floor mass/unit area ($kg/m^2$) including "smeared-out" stiffener masses. |
| 16 | 6-20 | E15.0 | $D'_{xp} = \left[\frac{EI}{d}\right]_{\substack{\text{long floor} \\ \text{beam}}} - \frac{E_x(t^3 - t_i^3)}{12(1-\nu^2)}$ (N.m) Additional bending rigidity of longitudinal floor beams/floor beam spacing. |
| | 21-35 | E15.0 | $D'_{yp} = \left[\frac{EI}{\ell}\right]_{\substack{\text{floor} \\ \text{support}}} - \frac{E_y(t^3 - t_i^3)}{12(1-\nu^2)}$ (N.m) Additional bending rigidity of transverse floor supports/support spacing. (Moments of inertia of stiffeners are to be computed about the floor centerline) |

| Card | Columns | Format | Description |
|---|---|---|---|
| 17 | 1-3 | A3 | END<br>End of Input Data<br><br>The following cards control the operations performed by the program. |
| 18 | 1-17 | A10,A7 | GENERATE MATRICES |
| 19 | 1-10 | A10 | CONSTRAINT |
| 20 | 1-5 | A5 | SHELL |
| 21 | 1-5 | A5 | PLATE |
| 22 | 1-3 | A3 | END |
| 23 | 1-5 | A5 | SOLVE |
| 24 | 1-5 | A5 | PUNCH Outputs to Tape 7. (Not Card Punch) |
| 25 | 1-11 | A11 | FREQUENCIES |
| 26 | 1-12 | A12 | EIGENVECTORS |
| 27 | 9-10 | I2 | 20 Number of eigenvectors (Generalized Coordinates) to be output (Maximum no. = 20, and Max.M x No. of eigenvectors $\leq$ 225) |
| 28 | 1-11 | A11 | MODE SHAPES |

| Card | Columns | Format | Description |
|---|---|---|---|
| 29 | 1-4 | A4 | TRAN Transverse mode shapes |
| | 38-40 | I3 | 20 Number of mode shapes to be output. |
| | 43-45 | I3 | 36 Number of increments for shell. [Displacements output at 5 degree intervals] |
| | 48-50 | I3 | 10 Number of increments for floor [Displacements output at intervals of floor width $L_p/20$]. |
| | 55 | L1 | T u and v displacements calculated |
| | 60 | L1 | T output required on Tape 7. |
| 30 | 1-3 | A3 | END |
| 31 | 1-10 | A10 | END OF JOB |
| 32 | 1 | 6/7/8/9 | End of file. |

No library subroutines are required. The program MRP must be run twice, once for SYMMETRIC modes and once for ANTISYMMETRIC modes. The same data is used in both cases except for Card 5.

### 5.2.2 Output File, Tape 7

The two output files, Tape 7, one for symmetric and one for anti-symmetric modes, must both be cataloged or stored for input to program MRPMOD. These output files may be large if axial mode orders M = 1 to 10 are all included and care should be taken to allow for this. For example, on the CDC NOS computing service, Tape 7 should be defined as a Direct Access File rather than an Indirect Access File which is limited in size.

For each value of M in turn, the output file, Tape 7, contains information on the first 20 normal modes including

Resonance frequencies
Generalized coordinates
Shell displacements
Floor displacements

### 5.2.3 Printed Output

Shell and Plate structural data.
For each value of M in turn:

Constraint matrices
Eigenvalues and Resonance frequencies
Generalized coordinates for first 20 modes
Shell and floor displacements for first 20 modes
Graphical representation of mode shapes.

## 5.3 Program MRPMOD

### 5.3.1 Input Data

| Card | Columns | Format | Description |
|---|---|---|---|
| 1 | 1-80 | 16A5 | Title card. This will be passed to program PAIN by Tape 9 output. |
| 2 | 1-5 | I5 | No. of terms used for shell displacement series in program MRP [Final $n_s + 1$] |
| | 6-10 | I5 | No. of terms used for floor displacement series in program MRP [Final $n_p + 1$] |
| 3 | 1-5 | I5 | No. of values of M in program MRP. Maximum no. of longitudinal half-wavelengths. |
| 4 | 1-5 | I5 | No. of terms used for shell displacement series in program PAIN [Maximum = 5] |
| | 6-10 | I5 | No. of terms used for floor displacement series in program PAIN [Maximum = 3] [For these, the most significant terms of the series will be selected by program MRPMOD] |
| 5 | 1-10 | F10.0 | Angle $\theta_o$ (degrees) at which the floor joint is located ($\theta_o = 0$ at bottom centerline) |

| Card | Columns | Format | Description |
|---|---|---|---|
| 6 | 1-10 | F10.0 | Cylinder length (m) |
| | 11-20 | F10.0 | Cylinder radius (m) |
| 7 | 1-10 | F10.0 | Shell mass/unit area ($kg/m^2$) including 'smeared-out' stiffener masses |
| | 11-20 | F10.0 | Floor mass/unit area ($kg/m^2$) including 'smeared-out' stiffener masses |
| 8 | 1-31 | 5X,I1,5A5 | TAPE 7 SYMMETRIC MODES |
| 9 | 1-31 | 5X,I1,5A5 | TAPE 8 ANTISYMMETRIC MODES |
| 10 | 1 | 6/7/8/9 | End of File. |

### 5.3.2 Input Files

Two files must be specified

Tape 7 - Symmetric modes output from Program MRP
Tape 8 - Antisymmetric modes output from Program MRP

### 5.3.3 Output File, Tape 9

The output file, Tape 9, must be cataloged or stored for input to program PAIN. Tape 9 contains information for all the modes, symmetric and antisymmetric for all values of M, arranged in ascending order of frequency. The output for each mode is

Frequency
Mode symmetry
Generalized mass
Most significant generalized coordinates for shell and floor
Shell displacements at 5 degree intervals

### 5.3.4 Printed Output

A summary is printed for each mode giving:

Frequency

Mode symmetry.

M = number of longitudinal half-wavelengths

$C^s_{Mn}$ = Most significant shell generalized coordinates (Max 5)

$n_s$ = number of shell circumferential waves, associated with each shell generalized coordinate

$C^p_{Mn}$ = Most significant floor generalized coordinates (Max 3)

$n_p$ = number of half-wavelengths in floor width associated with each floor generalized coordinate

Total generalized mass for the mode (kg)

Component of generalized mass due to shell normal displacement (kg)

Component of generalized mass due to floor normal displacement (kg)

## 5.4 Program PAIN

### 5.4.1 Input Data

| Card | Columns | Format | Description |
|---|---|---|---|
| 1 | 1-80 | 16A5 | Title card |
| 2 | 1-10 | F10.2 | Exterior air density ($kg/m^3$) |
| | 11-20 | F10.2 | Interior air density ($kg/m^3$) |
| | 21-30 | F10.2 | Exterior speed of sound (m/sec) |
| | 31-40 | F10.2 | Interior speed of sound (m/sec) |
| 3 | 1-5 | I5 | NI = Number of 1/3 octave band center frequencies (maximum 26) |

***The number of input data cards will vary depending on the value of NI, since the input format for frequencies, loss factors, etc. is 8F10.2. The card numbers that follow are correct only for 16<NI<25***

| Card | Columns | Format | Description |
|---|---|---|---|
| 4,5,6 | 1-10 | F10.2 | Lowest 1/3 octave band center frequency (Hz) |
| | 11-20 | F10.2 | 2nd 1/3 octave band frequency (Hz) [8 frequencies per card] |
| | | . | |
| | | . | |
| | | F10.2 | (NI)th 1/3 octave band freq. (Hz) |
| 7 | 1-10 | F10.2 | L = Fuselage cylinder length (m) |
| | 11-20 | F10.2 | a = cylinder radius (m) |
| | 21-30 | F10.2 | $\theta_o$ = angle at which floor joint is located (degrees) $\theta_o = 0$ is the bottom centerline |
| | 31-40 | F10.2 | $\nu$ = Poisson's ratio (for end caps) [At the moment, transmission through the end caps has not been included in the program, but this may be added later]. |
| 8 | 1-80 | 16A5 | Title card, describing the cavity |
| 9 | 1-10 | F10.2 | $L_c$ = Cavity length (m) |
| | 11-20 | F10.2 | d = distance of start of structure from start of cavity (d + ve $L<L_c$; d - ve $L>L_c$) |

| Card | Columns | Format | Description |
|---|---|---|---|
| 10 | 1-10 | F10.2 | The center frequency of the first 1/3 octave band in which the high-frequency formulation is used (Hz) (See Section 3 (8)) <br> If this value is zero, the program estimates a frequency. <br> If this value is non-zero, the input value is used, not the estimated value. |
| 11 | 1-25 | 5A5 | STRUCTURAL LOSS FACTORS |
| 12,13,14 | 1-10 | F10.2 | Structural loss factor for lowest frequency band. |
| | 11-20 | F10.2 | Structural loss factor for 2nd band. |
| | | . | |
| | | . | |
| | | F10.2 | Structural loss factor for (NI)th band. |
| 15 | 1-25 | 5A5 | ACOUSTIC LOSS FACTORS <br> The acoustic loss factors must be input for a bare fuselage. If the input loss factors are zero, then the cabin trim data is used to calculate them. |
| 16,17,18 | 1-10 | F10.2 | Acoustic loss factor for lowest frequency band (zero if calculated using trim data). |
| | 11-20 | F10.2 | Acoustic loss factor for 2nd band. |
| | | . | |
| | | . | |
| | | F10.2 | Acoustic loss factor for (NI)th band. |

| Card | Columns | Format | Description |
|---|---|---|---|
| 19 | 1-80 | 16A5 | Title card, describing the trim. |
| 20 | 1-10 | F10.2 | $h_t$ = insulation thickness (m) on curved wall of cylinder. |
| | 11-20 | F10.2 | $m_t$ = mass/unit area (kg/m$^2$) of the trim lining, facing the cavity. |
| | 21-30 | F10.2 | $A_t$ = Surface area (m$^2$) of the trim on the curved cylinder wall. |
| | 31-40 | F10.2 | $\eta_t$ = trim lining loss factor (in flexure). |

***If there is no trim, the value of $h_t = 0$ must be input and Cards 21-33, the remaining trim data, should be omitted. With no trim, the acoustic loss factors must be input on cards 16-18.***

If $h_t \neq 0$

| Card | Columns | Format | Description |
|---|---|---|---|
| 21 | 1-10 | F10.2 | $h_e$ = insulation thickness on end caps (m) |
| | 11-20 | F10.2 | $m_e$ = mass/unit area (kg/m$^2$) of the end cap trim lining, facing the cavity. |
| | 21-30 | F10.2 | $A_e$ = surface area (m$^2$) of the trim on one end cap. |
| | 31-40 | F10.2 | $\eta_e$ = end cap trim lining loss factor (in flexure) |

***For each frequency band, the trim insulation characteristics are input. (For Fiberglas Type PF105, the values are given in Ref.[3], Page 482)***

| Card | Columns | Format | Description |
|---|---|---|---|
| 22,23,24 | 1-10 | F10.2 | $\alpha$ = attenuation constant (dB/m) for first frequency band. |
| | 11-20 | F10.2 | $\alpha$ for 2nd frequency band. |
| | | . | |
| | | . | |
| | | . | |
| | | F10.2 | $\alpha$ for (NI)the frequency band. |
| 25,26,27 | 1-10 | F10.2 | $\lambda_m$ = acoustic wavelength in material (m) for first frequency band. |
| | 11-20 | F10.2 | $\lambda_m$ for 2nd frequency band. |
| | | . | |
| | | . | |
| | | . | |
| | | F10.2 | $\lambda_m$ for (NI)th frequency band. |
| 28,29,30 | 1-10 | F10.2 | $\|W\|$ = amplitude of wave impedance (mks rayls) of trim insulation for first frequency band |
| | 11-20 | F10.2 | $\|W\|$ for 2nd frequency band. |
| | | . | |
| | | . | |
| | | . | |
| | | F10.2 | $\|W\|$ for (NI)th frequency band. |

| Card | Columns | Format | Description |
|---|---|---|---|
| 31,32,33 | 1-10 | F10.2 | $\phi$ = phase of wave impedance (degrees) for first frequency band [+ve values] |
| | 11-20 | F10.2 | $\phi$ for 2nd frequency band. |
| | | . | |
| | | . | |
| | | F10.2 | $\phi$ for (NI)th frequency band. |
| 34 | 1-15 | 3A5 | PROPELLER TONES |
| 35 | 1-80 | 16A5 | Title card, describing the propeller data. Propeller location is $(r_p, \phi, z_p)$[See Figure 2] |
| 36 | 1-10 | F10.2 | $r_p$ = distance of propeller center-line from fuselage centerline (m) |
| | 11-20 | F10.2 | $\phi$ = angle between vertical and the line from propeller to fuselage centerline (degrees) [$\phi$ must be given to the nearest 5 degrees] |
| | 21-30 | F10.2 | $z_p$ = distance of propeller plane from forward end of fuselage (m) |
| | 31-40 | F10.2 | B = No. of blades of propeller. |
| | 41-50 | F10.2 | Propeller rpm, for which propeller sound pressures were predicted. |

| Card | Columns | Format | Description |
|---|---|---|---|
| 36 | 51-60 | F10.2 | +1.0 If propeller rotates counter-clockwise in z direction (as in Figure 3); or -1.0 if propeller rotates clockwise in z direction.<br><br>(Input data created using ANOPP must be blade downsweep only) |

***The propeller pressure signature is defined at grid points on the upper quarter of the fuselage skin, and input, using a Fourier series analysis, as the amplitude and phase at the propeller harmonics for each grid point. The output from a propeller noise prediction program [1] has been used as part of this data input package. The location of the grid points is defined in Figure 3.***

| Card | Columns | Format | Description |
|---|---|---|---|
| 37 | 1-5 | I5 | $H_{max}$ = No. of propeller harmonics (Maximum = 10). |
| | 6-10 | I5 | $k_{max}$ = Number of axial grid coordinates (Maximum = 16). |
| | 11-15 | I5 | $k_p$ = Axial grid coordinate at which propeller plane is located. |

The following ($H_{max}$ x $k_{max}$ x10) cards contain the pressure amplitude and phase for every grid point ($k,\ell$) for all the propeller harmonics H.

| Card | Columns | Format | Description |
|---|---|---|---|
| 38 | 1-4 | I4 | k = Grid axial coordinate |
| onwards | 5-8 | I4 | $\ell$ = Grid circumferential coordinate |

| Card | Columns | Format | Description |
|---|---|---|---|
| 38 onwards (contd) | 9-14 | F6.2 | $x_1$ ANOPP coordinates defined in Figure 3 (not used by Program PAIN) |
| | 15-20 | F6.2 | $x_2$ |
| | 21-26 | F6.2 | $x_3$ |
| | 27-32 | I6 | H = harmonic number. |
| | 33-48 | E16.5 | $\phi_H(k,\ell)$ = phase of Fourier component for harmonic H at location $(k,\ell)$ (degrees) |
| | 49-64 | E16.5 | $A_H^{(k,\ell)}$ = amplitude of Fourier component for Harmonic H at location $(k,\ell)$ (Pa) |

This format is repeated until all values of k, $\ell$ and H have been used.

| | | |
|---|---|---|
| 1 | 6/7/8/9 | End of file. |

No library subroutines are required.

### 5.4.2 Input Files

Two files must be specified.

Tape 9 - Structural modes output from program MRPMOD.
Tape 11 - Acoustic modes output from program CYL2D.

### 5.4.3 Printed Output

1. Band-averaged loss factors

Acoustic loss factor $\bar{\eta}_n$, either input or calculated values when trim is present
Structural loss factors $\eta_r^{struc}$ input
External radiation loss factors $\eta_r^{rad}$
Total structural loss factor $\bar{\eta}_r'$ when trim is present.

2. Trim Data

Trim characteristics input

Trim transmission coefficient (dB) 10 log $(1/\tau_t)$

Trim and end cap admittances, real and imaginary. (non-dimensional)

3. Number of structural and acoustic modes in each 1/3 octave frequency band.

4. Structural Modes. For each mode:

Frequency

Symmetry

Total structural loss factor $\eta_r'$

M = number of longitudinal half-wavelengths

For the most significant displacement series terms for shell and floor:-

$n_s$ = number of circumferential wavelengths for shell

$C_{Mn}^{s}$ = generalized coordinate for shell

$n_p$ = number of transverse half-wavelengths for floor

$C_{Mn}^{p}$ = generalized coordinate for floor

Total generalized mass (kg)

Gen. mass associated with shell normal displacement (kg)

Gen. mass associated with floor normal displacement(kg)

Reverberant field joint acceptance $j^{2(rev)}$

5. Acoustic modes. For each mode:

Frequency

Symmetry

q = no. of longitudinal half-wavelengths

i = mode counter for cylinder cross-section modes.

Acoustic loss factor $\eta_n$.

Normalization parameter $\epsilon_n$.

6. Acoustic/structural coupling factors.

For acoustic mode n = (q,i) and structural mode r = (M,N) let

$$f'(n,r) = f_{qM} \cdot f_{iN} \quad \text{(see Volume I, Section 3.5)}$$

Values of $f_{iN}$ are output for both shell and floor.

7. Propeller Pressure Amplitude and Phase

Output for all grid points, both above and below $\theta = \phi$, for each propeller harmonic,
Pressure amplitude (dB re 20 microPa) including reflecting surface effects.
Pressure Phase (degrees)

8. Propeller generalized forces.

For each harmonic H and structural mode r,
Generalized force $\Psi_G(r,H)$ - (see Ref.[2], Equation 42).

9. Tone Transmission for Propeller Harmonics -

Interior space-averaged mean square pressure (dB re 20 microPa)

1) Low frequency formulation calculations only, for all harmonics, identifying 5 modes making the largest contributions. $\eta_r''$ output to identify closely coupled structural and acoustic modes.

2) Summary of low frequency formulation (where specified) and the high frequency formulation (expected value) for all harmonics.

3) Summary of predicted interior space-averaged mean square pressure (dB re 20 microPa).

## 6.0 CONTROL CARDS FOR EXECUTING THE PROGRAM

The control cards that follow are for the CDC CYBERNET NOS Computing Service. All the programs, CYL2D, MRP, MRPMOD and PAIN, are written in Fortran Extended 4, and comply with ANSI 1966 Fortran for the most part, except where specific CDC functions such as EOF were required. In addition, it is assumed that IMSL library subroutines are available for program CYL2DF.

The control cards assume that the Fortran programs are stored as permanent files on disc storage with the names CYL2DF, MRPF, MRPMODF and PAIN. Input and output data are also stored as permanent files. Sample input data for each program are also given.

## 6.1 Control Cards and Data for Program CYL2D

```
/JOB
PAIN.T150.P4.
/USER
/CHARGE
ROUTE.OUTPUT.DC=PR.UN=*******.ST=***.DEF.
GET.CYL2DF.                                   Fortran Program CYL2DF
FTN.R=3.
REWIND.LGO.
REPLACE.LGO=CYL2DC.                           Compiled Program CYL2DC
GOTO.1.
EXIT.
1.STIME.
DAYFILE.
/EOR
/READ.CYL2DF
/EOF
```

```
/JOB
PAIN.T400.P4.
/USER
/CHARGE
ROUTE.OUTPUT.DC=PR.UN=*******.ST=***.DEF.
GET.CYL2DD.                                   Input Data File CYL2DD
ATTACH.IMSL/UN=LIBRARY.                       Library Subroutines
$LIBRARY.IMSL.
GET.CYL2DC.                                   Compiled Program CYL2DC
COPYBF.CYL2DC.LGO.
LDSET(PRESET=ZERO)
LGO.PL=50000.
REPLACE.TAPE11=CYL56.                         Output file CYL56
GOTO.1.
EXIT.
1.STIME.
DAYFILE.
/EOR
/READ.CYL2DD
/EOF
```

CYL2DD **Input Data File**

56.6

## 6.2 Control Cards and Data for Program MRP

```
/JOB
PAIN,T150,P4.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,MRPF.                                  Fortran Program MRPF
FTN,R=3.
REWIND,LGO.
REPLACE,LGO=MRPC.                          Compiled Program MRPC
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,MRPF
/EOF
```

**Control Cards for Symmetric Modes**

```
/JOB
PAIN,T400,P1.
/USER
/CHARGE
ROUTE.OUTPUT,DC=PR,UN=*******,ST=***,DEF.
DEFINE,TAPE7=MRPSM.        Direct Access Output File MRPSM
GET,MRPSD.                 Input Data File MRPSD
GET,MRPC.                  Compiled Program MRPC
COPYBF,MRPC,LGO.
LDSET(PRESET=ZERO)
LGO,PL=50000.
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,MRPSD
/EOF
```

**Control Cards for Antisymmetric Modes**

```
/JOB
PAIN,T400,P1.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***.DEF.
DEFINE,TAPE7=MRPAM.                     Direct Access Output File MRPAM
GET,MRPAD.                              Input Data File MRPAD
GET,MRPC.
COPYBF,MRPC,LGO.                        Compiled Program MRPC
LDSET(PRESET=ZERO)
LGO,PL=50000.
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,MRPAD
/EOF
```

## MRPSD Input Data File for Symmetric Modes

```
 STIFFENED .032 IN CYLINDER. 20 IN RADIUS. WITH FLOOR AT 56.6 DEGREES.
 MODEL #5 CYLINDER.  PHASE III.
   FREELY SUPPORTED END CONDITIONS. RIGID JOINT AT FLOOR-CYLINDER JUNCTION
   SYMMETRIC MODES.  OUTPUT ON MRPSM FOR M=1-10 MODES
END
INPUT DATA
GENERAL
     FREELY SUPPORTED                 RIGID                               SYMMETRIC
               56.6
        1    10     1     0    12     1     0     5     1
        T     T     F
SHELL
        7.239495E10     7.239495E10                  .33                 .33
        0.001153058        3.113933                0.508              1.8034
          62.352938     1.200725E4
PLATE
        7.239495E10     7.239495E10                  .33                 .33
         0.00127622       3.4465372
        8.6297699E3     5.4264354E3
END
GENERATE MATRICES
CONSTRAINT
SHELL
PLATE
END
SOLVE
PUNCH
FREQUENCIES
EIGENVECTORS
       15
MODE SHAPES
TRAN                                         15    36    10     T     T
END
END OF JOB
```

## MRPAD Input Data File for Antisymmetric Modes

```
 STIFFENED .032 IN CYLINDER, 20 IN RADIUS, WITH FLOOR AT 56.6 DEGREES.
 MODEL #5 CYLINDER.  PHASE III.
   FREELY SUPPORTED END CONDITIONS, RIGID JOINT AT FLOOR-CYLINDER JUNCTION
   ANTISYMMETRIC MODES.  OUTPUT ON MRPAM FOR M=1-10 MODES
END
INPUT DATA
GENERAL
     FREELY SUPPORTED              RIGID                          ANTISYMMETRIC
               56.6
         1    10    1    0   12    1    0    5    1
         T    T     F
SHELL
         7.239495E10   7.239495E10        .33         .33
         0.001153058      3.113933      0.508      1.8034
           62.352938    1.200725E4
PLATE
         7.239495E10   7.239495E10        .33         .33
          0.00127622     3.4465372
         8.6297699E3   5.4264354E3
END
GENERATE MATRICES
CONSTRAINT
SHELL
PLATE
END
SOLVE
PUNCH
FREQUENCIES
EIGENVECTORS
        15
MODE SHAPES
TRAN                                      15    36    10    T    T
END
END OF JOB
```

## 6.3 Control Cards and Data for Program MRPMOD

```
/JOB
PAIN,T150,P4.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,MRPMODF.                 Fortran Program MRPMODF
FTN,R=3.
REWIND,LGO.
REPLACE,LGO=MRPMODC.         Compiled Program MRPMODC
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,MRPMODF
/EOF
```

```
/JOB
PAIN,T400,P3.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,MRPMODD.                 Input data file MRPMODD
ATTACH,TAPE7=MRPSM.          Symmetric Modes File MRPSM
ATTACH,TAPE8=MRPAM.          Antisymmetric Modes File MRPAM
GET,MRPMODC.                 Compiled Program MRPMODC
COPYBF,MRPMODC,LGO.
LDSET(PRESET=ZERO)
LGO,PL=50000.
REPLACE,TAPE9=STR56.         Output File STR56
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,MRPMODD
/EOF
```

**MRPMODD Input Data File**

```
 STIFFENED .032 IN CYLINDER, WITH STIFFENED FLOOR AT 56.6 DEGREES
   13     6
   10
    5     3
56.6
1.8034     0.508
3.11324    3.44578
TAPE 7 SYMMETRIC MODES
TAPE 8 ANTISYMMETRIC MODES
```

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

## 6.4 Control Cards and Data for Program PAIN

```
/JOB
PAIN,T150,P4.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,PAIN.                          Fortran Program PAIN
FTN,R=3.
REWIND,LGO.
REPLACE,LGO=PAINC.                 Compiled Program PAINC
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,PAIN
/EOF
```

```
/JOB
PAIN,T400,P3,CM370000.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,PAIND.                         Input Data File PAIND
GET,TAPE9=STR56.                   Structural Modes File STR56
GET,TAPE11=CYL56.                  Acoustic Modes File CYL56
GET,PAINC.                         Compiled Program PAINC
COPYBF,PAINC,LGO.
LDSET(PRESET=ZERO)
LGO,PL=50000.
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,PAIND
/EOF
```

## 6.4 Control Cards and Data for Program PAIN

```
/JOB
PAIN,T150,P4.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,PAIN.                      Fortran Program PAIN
FTN,R=3.
REWIND,LGO.
REPLACE,LGO=PAINC.             Compiled Program PAINC
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,PAIN
/EOF
```

```
/JOB
PAIN,T400,P3,CM370000.
/USER
/CHARGE
ROUTE,OUTPUT,DC=PR,UN=*******,ST=***,DEF.
GET,PAIND.                     Input Data File PAIND
GET,TAPE9=STR56.               Structural Modes File STR56
GET,TAPE11=CYL56.              Acoustic Modes File CYL56
GET,PAINC.                     Compiled Program PAINC
COPYBF,PAINC,LGO.
LDSET(PRESET=ZERO)
LGO,PL=50000.
GOTO,1.
EXIT.
1,STIME.
DAYFILE.
/EOR
/READ,PAIND
/EOF
```

## REFERENCES


1. Padula, S.L., and Block, P.J.W., "Acoustic Prediction Methods for the NASA Generalized Advanced Propeller Analysis System," AIAA Paper 84-2243, July 1984.

2. Pope, L.D., Wilby, E.G., and Wilby, J.F., "Propeller Aircraft Interior Noise Model," NASA CR 3813, 1984.

3. Beranek, L.L., "Noise and Vibration Control," McGraw-Hill Book Company, 1971.




PRECEDING PAGE BLANK NOT FILMED

## APPENDIX A

## LIST OF SYMBOLS

$A_e$ ($m^2$) Surface area of trim on one end cap.

$A_H^{(k,\ell)}$(Pa) Amplitude of Fourier component of propeller pressure signature at propeller harmonic H and grid location $(k,\ell)$

$A_R$ ($m^2$) Cross-sectional area of ring frames on the shell (or transverse floor supports)

$A_S$ ($m^2$) Cross-sectional area of stringers on the shell (or longitudinal floor beams)

$A_t$ ($m^2$) Surface area of trim on the curved cylinder wall.

a (m) Cylinder radius

$a_o^{k,\ell}/2$(Pa) Mean propeller pressure amplitude at grid location $(k,\ell)$

B Number of propeller blades

BPF = NB/60 (Hz) Blade passage frequency

$C_{Mn}^{Pr}, C_{Mn}^{Sr}$ Floor and shell generalized coordinates for structure mode $r = (M,N)$

$c_{oI}$ (m/sec) Interior speed of sound

d (m) Spacing between stringers (or floor beams)

d (m) Distance of start of structure from start of cavity [d + ve $L < L_c$; d - ve $L > L_c$]

## LIST OF SYMBOLS
## (Continued)

| | |
|---|---|
| $E$ $(N/m^2)$ | Stiffener modulus of elasticity |
| $E_x$ $(N/m^2)$ | Shell or floor modulus of elasticity in axial direction |
| $E_y$ $(N/m^2)$ | Floor modulus of elasticity in the transverse direction |
| $E_\theta$ $(N/m^2)$ | Shell modulus of elasticity in circumferential direction |
| $f'(n,r) = f_{qM}f_{iN}$ | Acoustic/structural coupling factor for acoustic mode $n = (q,i)$ and structural mode $r = (M.N)$ [see Ref.[2] Section 3.5] |
| $G_{x\theta}$ $(N/m^2)$ | Shell or floor shear modulus |
| $H$ | Propeller harmonic order |
| $H_{max}$ | Maximum number of propeller harmonics considered |
| $h_e$ (m) | Insulation thickness on end caps |
| $h_t$ (m) | Insulation thickness on curved wall of cylinder |
| $I$ $(m^4)$ | Moment of inertia of stiffener about shell or floor middle surface |
| $i$ | Acoustic mode number counter for cylinder cross-section modes, associated with mode $n \equiv (q,i)$ |
| $j^2(rev)$ | Reverberant field joint acceptance for each structural mode |

## LIST OF SYMBOLS
## (Continued)

| | |
|---|---|
| $k$ | Axial grid coordinate (non-dimensional) for point $(k,\ell)$ |
| $k_p$ | Axial grid coordinate at which propeller plane is located |
| $k_{max}$ | Maximum number of axial grid coordinates |
| $k = 2\pi/\lambda$ | Acoustic wave number |
| $L$ (m) | Cylinder length (not including end caps) |
| $L_c$ (m) | Cylinder cavity length |
| $L_p$ (m) | Floor width (wall to wall) |
| $\ell$ | Circumferential grid coordinate (non-dimensional) for point $(k,\ell)$ |
| $M$ | Number of longitudinal half-wavelengths for structural mode |
| $m = \rho t$ (kg/m$^2$) | Average surface mass of the shell or floor |
| $m_e$ (kg/m ) | Mass/unit area of end cap trim lining, facing the cavity |
| $m_t$ (kg/m ) | Mass/unit area of cylinder wall trim lining, facing the cavity |
| $N$ | Propeller rpm |
| $N$ | Structural mode number *counter* only, associated with mode $r \equiv (M,N)$ |

## LIST OF SYMBOLS
## (Continued)

| | |
|---|---|
| NI | Number of one-third octave band center frequencies (Max 26) |
| $n$ | Acoustic mode number $n \equiv (q,i)$ |
| $n_s$ | Number of shell circumferential waves |
| $n_p$ | Number of half-wavelengths in floor width |
| $n^*$ | Number of terms in displacement series for shell or floor |
| $p[(k,\ell),t]$ (Pa) | Propeller pressure at time t at grid location $(k,\ell)$ |
| $q$ | Number of longitudinal half-wavelengths for acoustic mode, associated with mode $n \equiv (q,i)$ |
| $R_p$ (m) | Propeller radius |
| $r$ | Structural mode number $r \equiv (M,N)$ |
| $r_p$ (m) | Radial distance from center of fuselage cylinder to the axis of rotation of the propeller |
| $T_1 = BPF^{-1}$ (secs) | Period of propeller noise signature |
| $t$ (secs) | Time coordinate, over propeller noise period $t=0$ to $T_1$ |
| $t$ (m) | Equivalent thickness of shell or floor (see page 10) |
| $t_i$ (m) | Actual thickness of shell or floor |

# LIST OF SYMBOLS
(Continued)

| | |
|---|---|
| $u,v,w$ | Shell and floor degrees of freedom |
| $V$ ($m^3$) | Cavity volume, above the floor |
| $\lvert W \rvert$ (mks rayls) | Amplitude of wave impedance of trim insulation |
| $x,y,z$ | Co-ordinate system (see Figure 3) |
| $x_1 x_2 x_3$ | Local coordinate system used for ANOPP propeller noise prediction (see Figure 3) |
| $z_p$ (m) | Location of propeller relative to the front of the cylinder (of length L) |
| $\alpha$(dB/m) | Trim insulation attenuation constant |
| $\Delta = \frac{\pi a}{18}$(m) | Grid spacing for propeller noise predictions |
| $\varepsilon_n$ | Acoustic mode n normalization parameter (see Ref.[2]. |
| $\eta_e$ | End cap trim lining loss factor (in flexure) |
| $\eta_n$ | Acoustic loss factor for mode n |
| $\bar{\eta}_n$ | Average one-third octave band acoustic loss factor |
| $\eta_t$ | Cylinder trim lining loss factor (in flexure) |
| $\eta_r^{struc}$ | Average one-third octave band structural loss factor |
| $\eta_r^{rad}$ | Average one-third octave band external radiation loss factor |

## LIST OF SYMBOLS
## (Continued)

| | |
|---|---|
| $\eta_r'$ | Total structural loss factor, including effect of trim |
| $\bar{\eta}_r'$ | Average one-third octave band total structural loss factor, including trim |
| $\eta_r''$ | Internal radiation loss factor, due to closely coupled structural and acoustic modes (see Page 43, Ref.[2]). |
| $\theta$(degrees) | Shell angular coordinate (see Figure 3). $\theta = 0$ is at fuselage bottom centerline |
| $\theta_o$(degrees) | Angle at which shell/floor joint is located |
| $\lambda_m$(m) | Acoustic wavelength in trim insulation |
| $\nu_x \nu_\theta \nu_y$ | Poisson's ratio for shell or floor |
| $\nu$ | Poisson's ratio for end caps |
| $\rho$(kg/m$^3$) | Density of shell or floor material |
| $\tau_t$ | Trim transmission coefficient = $-10 \log (\tau_t)$ dB |
| $\phi$(degrees) | Angular position of propeller hub relative to fuselage bottom centerline (see Figure 2) |
| $\phi$(degrees) | Phase of wave impedance of trim insulation |
| $\phi_H^{(k,\ell)}$(degrees) | Phase of Fourier component of propeller pressure signature at propeller harmonic H and grid location $(k,\ell)$ |
| $\psi_S^r(z,\theta)$ | Shell displacement at location $(z,\theta)$ in mode r |

## LIST OF SYMBOLS
## (Continued)

$\psi_p^r(z,x)$ Floor displacement at location (z,x) in mode r

$\Psi_G(r,H)$ Generalized modal forcing function due to propeller noise, mode r at propeller harmonic H

$\omega$ (radians/sec) Angular frequency

$\omega_H$ (radians/sec) Angular frequency of propeller harmonic H

# BIBLIOGRAPHIC DATA SHEET

| | | |
|---|---|---|
| 1. Report No. NASA CR-172425 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle PROPELLER AIRCRAFT INTERIOR NOISE MODEL - USERS' MANUAL FOR COMPUTER PROGRAM | | 5. Report Date January 1985 |
| | | 6. Performing Organization Code |
| 7. Author(s) E. G. WILBY, L. D. POPE | | 8. Performing Organization Report No. 5058 |
| 9. Performing Organization Name and Address BOLT BERANEK AND NEWMAN INC. 21120 Vanowen Street Canoga Park, CA 91303 | | 10. Work Unit No. |
| | | 11. Contract or Grant No. NAS1-15782 |
| 12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, DC 20546 | | 13. Type of Report and Period Covered Contractor Final Report |
| | | 14. Sponsoring Agency Code 505-33-53 |

15. Supplementary Notes

Technical Representative of Contracting Officer:
William H. Mayes, Langley Research Center

16. Abstract

A computer program entitled **PAIN** (Propeller Aircraft Interior Noise) has been developed to permit calculation of the sound levels in the cabin of a propeller-driven airplane. The fuselage is modeled as a cylinder with a structurally integral floor, the cabin sidewall and floor being stiffened by ring frames, stringers and floor beams of arbitrary configurations. The cabin interior is covered with acoustic treatment and trim. The propeller noise consists of a series of tones at harmonics of the blade passage frequency.

Input data required by the program include the mechanical and acoustical properties of the fuselage structure and sidewall trim. Also, the precise propeller noise signature must be defined on a grid that lies in the fuselage skin. The propeller data are generated with a propeller noise prediction program such as the NASA Langley ANOPP program. The program PAIN permits the calculation of the space-average interior sound levels for the first ten harmonics of a propeller rotating alongside the fuselage. User instructions for PAIN are given in the report. Development of the analytical model is presented in NASA CR 3813.

| | |
|---|---|
| 17. Key Words (Selected by Author(s)) Aircraft Interior Noise, Propeller Noise, Acoustic Power Flow | 18. Distribution Statement [redacted] Subject Category 71 |

| | | | |
|---|---|---|---|
| 19. Security Classif. (of this report) Unclassified | 20. Security Classif. (of this page) Unclassified | 21. No. of Pages 58 | 22. Price |

Available: NASA's Industrial Applications Centers